NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WEATHER PROGRAMS

The National Aeronautics and Space Administration (NASA) Headquarters Weather Support Office has continued to improve NASA's weather support capabilities for both manned and unmanned space launch vehicles. It is expected that these improvements will strengthen and enhance the information provided to the ground-based decision-makers and astronaut observers to insure that NASA achieves the best operational posture for Space Shuttle launches and landings. The goal of the operations program is to provide the specialized meteorological data needed by operational forecasters at Cape Canaveral Air Station of Kennedy Space Center (KSC) and Johnson Space Center to support the Space Shuttle program. The focus is on detecting and forecasting the mesoscale weather events which strongly impact Shuttle ground processing, launches, and landing operations.

OPERATIONS

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This operations program requires exploitation of the latest technology. The Applied Meteorology Unit (AMU), collocated with the Air Force's Range Weather Operations, provides a facility to evaluate and, if warranted, transition new meteorological technology into operations. For instance, the AMU strives to develop techniques and systems to help predict and avoid the impacts of KSC's frequent mesoscale summer thunderstorms which endanger the ground processing, launch, and landing operations of the American Space Program--Space Shuttle, DOD, and commercial. Special attention has been given to evaluating mesoscale numerical models. The AMU functions under a joint NASA, Air Force, and NWS Memorandum of Agreement. Development of an Advanced Algorithm for the LDAR system will conclude in FY 1998, leaving only operational implementation in FY 1999. Development of the Very Short Baseline LDAR system should be mostly complete by FY 1998. After development, the technology will be transferred to a commercial firm, GAI, which is currently working under a Space Act Agreement with NASA to commercialize LDAR. A new Airborne Field Mill (ABFM) data gathering program is under study at KSC. If approved, funds will be forwarded to NASA/Marshall Space Flight Center to purchase ABFM for the program.

SUPPORTING RESEARCH

The supporting research activities are sponsored by the NASA's Office of Earth Science (OES). The purpose of NASA's Earth Science Enterprise is to understand the total earth system and the effects of natural and human-induced changes on the global environment. Earth Science is pioneering the new interdisciplinary field of research called earth system science, born of the recognition that the earth's land surface, oceans, atmosphere, ice sheets and biota are both dynamic and highly interactive. It is an area of research with immense benefits to the nation, yielding new knowledge and tools for weather forecasting, agriculture, water resource management, urban and land use planning, and other areas of economic and environmental importance. In concert with other agencies and the global research community, Earth Science is providing the scientific foundation needed for the complex policy choices that lie ahead on the road to sustainable development. Earth Science has established three broad goals: (1) expand scientific knowledge of the earth system using NASA's unique capabilities from the vantage points of space, aircraft and *in situ* platforms; (2) disseminate information about the earth system; and (3) enable productive use of Earth Science program science and technology in the public and private sectors. The Earth Science Enterprise has evolved from what was previously called the Mission to Planet Earth Enterprise.

The pursuit of earth system science would be impractical without the continuous, global observations provided by satellite-borne instruments. Earth Science comprises an integrated slate of spacecraft and *in situ* measurement capabilities; data and information management systems to acquire, process, archive and distribute global data sets; and research and analysis programs to convert data into new knowledge of the earth system. Numerous users in academia, industry, federal, state and local government tap this knowledge to produce products and services essential to achieving sustainable development. Earth Science is NASA's contribution to the United States Global Change Research Program (GCRP), an interagency effort to understand the processes and patterns of global change.

Nearly all of NASA's funding in meteorology is for supporting research. This supporting research funding is contained in four major line items of the Office of Earth Science budget. These line items are: (1) Earth Observing System; (2) Earth Observing System Data Information System; (3) Earth Probes; and, (4) applied research and data analysis.

The overall goal of the Earth Observing System (EOS) is to advance the understanding of the entire earth system on a global scale by improving our knowledge of the components of the system, the interactions between them, and how the earth system is changing. The EOS data will be used to study the atmosphere, oceans, cryosphere, biosphere, land surface and solid earth, particularly as their interrelationships are manifested in the flow of energy and in the cycling of water and other chemicals through the earth system.

The EOS program mission goals are: (1) to create an integrated, scientific observing system emphasizing climate change, that will enable multi-disciplinary study of the earth's critical, life-enabling, interrelated processes; (2) to develop a comprehensive data information system, including a data retrieval and processing system; (3) to serve the needs of scientists performing an integrated multi-disciplinary study of planet earth and to make Earth Science data and information publicly available; and, (4) to acquire and assemble a global database for remote sensing measurements from space over a decade or more to enable definitive and conclusive studies of earth system attributes.

The goals for the EOS Data Information System (EOSDIS) are the development and operation of a highly integrated system which can: (1) operate the EOS satellites; (2) acquire instrument data; (3) produce data and information products from the EOS to preserve these and all other Earth Science environmental observations for continuing use; and (4) make all these data and information easily available for use by the research, education, government agencies and all those who can benefit from them in making economic and policy decisions. The EOSDIS facilitates the goals of Earth Science by enabling the public to benefit fully from increased understanding and observations of the environment.

The Earth Probes program is the component of Earth Science that addresses unique, specific, highly-focused mission requirements in earth science research. The program was designed to have the flexibility to take advantage of unique opportunities presented by international cooperative efforts or technical innovation, and to complement the EOS by providing the ability to investigate processes that require special orbits or have unique requirements. The currently approved earth probes are the Total Ozone Mapping Spectrometer (TOMS), Tropical Rainfall Measuring Mission (TRMM), Lewis & Clark, Earth System Science Pathfinders (ESSP), and LightSAR.

The goal of applied research and data analysis is to advance our understanding of the global climate environment, the vulnerability of the environment to human and natural forces of change, and the provision of numerical models and other tools necessary for understanding global climate change.

The applied research and data analysis program is divided into two components: Earth Science program science and Earth Science operations, data retrieval, and storage. The activities under Earth Science program science include research and analysis, EOS science, airborne science and applications, the purchase and management of scientific data, commercial remote sensing and Uncrewed Aerial Vehicle (UAV) science program. Operations, data retrieval and storage consists of several independent activities responsible for the operation of currently functioning spacecraft and flight instruments, high performance computing and communications, and the provision of computing infrastructure. Each of the major components of applied research and data analysis has its own set of goals, strategies for achieving goals, performance measures, and accomplishments and plans.

The goal for the science program is to contribute to the integration of the earth and environmental sciences into an interdisciplinary scientific understanding of the earth system and the effects of humankind on the global environment. Major emphasis is placed on providing early warning and fast response to global environmental changes which pose risks to society. The science program also provides the analysis and integration of critical data and models needed for national and international assessments. An objective of current planning is to achieve the most essential, long-term objectives of EOS, and to increase effort on science with near-term payoff, within a sustainable level of funding. The observational program will become resilient, better, and cheaper in the future by: (1) taking advantage of the experience being gained in preparation of the first round of EOS flight missions to reduce observing requirements in the future and to simplify the design of instruments for more cost-effective continued operation, (2) finding alternative means to carry out some of the essential measurements at the same level of quality through cooperation with other agencies and nations, and (3) infusing new ideas and technologies into the EOS program through small satellite missions that have lower infrastructure and flight costs.

The Research and Analysis science program is essential to the discovery of new concepts and to the design of future missions. The primary mode of research coordination occurs through the USGCRP, the Committee on the Environment and Natural Resources (CENR) Subcommittee on Global Change Research, and the various boards and committees at the National Academy of Science.

The strategy of interdisciplinary research is to increase scientific understanding of the global environment and its vulnerability to both human and natural factors of change (e.g. pollution, climate variability, deforestation). Viewing the earth from space is essential to comprehending the cumulative influence of human activities on its natural resource base. An important priority is to provide accurate assessment of the extent and health of the world's forest, grassland, and agricultural resources. Observations from space are the only source of objective information on the human use of land in a time of rapid land use development. A related priority is to improve understanding and prediction of transient climate variation, such as El Niño anomalies. Reducing uncertainties in climate predictions a season or a year in advance would dramatically improve agriculture and energy utilization planning. Natural hazards research is exploring the use of remote sensing observations for mitigation of drought and flood consequences. There is increasing evidence that predictions of extreme weather events can be improved by understanding their links to interannual climate phenomena like El Niño events. Special attention is being given to measuring and modeling the effects of relative forces like clouds, aerosols and greenhouse gases in long-term climate change, in order to improve our assessments of climate trends on time scales of decades to centuries. A continuing priority is understanding the causes and consequences of changes in atmospheric ozone. Emphasis is now being placed on the changing composition of the lower atmosphere, which is sensitive to the unprecedented increase of pollutant emissions in rapidly developing regions throughout the world. Work will continue in the core research programs in Earth Science.

EOS interdisciplinary science consists of focused research projects to analyze specific Earth Science data sets and interdisciplinary investigations geared for a broader probe into Earth Science system functions. The former is needed to control quality of data produced by interdisciplinary instrument computing facilities and the latter for bridging disciplinary boundaries. Both types of efforts are being supplemented by graduate student participation in the EOS science fellowship program.

There are currently over 1,700 scientific investigations being funded under the research and analysis program. Approximately 900 are carried out by universities, 100 by national research laboratories, and 700 by federal government agencies. The distribution of the activities encompasses forty-five of the fifty states.

The airborne science program funds operations of two ER-2 and one DC-8 aircraft. A C-130Q is also being used to support selected Earth Science investigations. The program funds operation and support of a core of remote sensing instruments and a facility for analyzing and calibrating data from those instruments. The specifically modified aircraft serve as test beds for newly developed instrumentation and their algorithms prior to spaceflight. The instrumented aircraft provide remote sensing and *in situ*

measurements for many Earth Science research and analysis field campaigns, including stratospheric ozone, tropospheric chemistry, and ecological studies throughout the world. The ER-2 aircraft, in particular, are unique in that they are the highest flying subsonic civilian research aircraft and were key in collecting *in situ* data for our understanding of ozone depletion and stratospheric transport mechanisms. The DC-8 aircraft provides a unique "flying laboratory" facility for a broad range of disciplines in atmospheric sciences.

The objectives of the mission science team/guest investigators are to analyze data sets from operational spacecraft that support global climate change research in atmospheric ozone and trace chemical species, the earth's radiation budget, aerosols, sea ice, land surface properties, and ocean circulation and biology. Funding provides for analyzing data from the Upper Atmosphere Research Satellite (UARS), Topography Experiment (TOPEX), Earth Radiation Budget Satellite (ERBS) spacecraft and spaceborne instruments such as Solar Backscatter Ultraviolet (SBUV/2), TOMS, and TRMM.

The advanced geostationary studies will investigate the application of the latest technology in developing small compact geostationary satellites that will support both research and operational objectives. For example, one candidate under consideration has the capability to provide the first adequately calibrated observations from geostationary orbit that support climate research. The satellite and instrument would be developed over a four year time period. The first spacecraft would carry an imager and a second spacecraft would carry a sounder. The imager has spectral bands which provide data on cloud albedo, vegetation, cirrus clouds, cloud ice, limited ozone, and both high-level and low-level water vapor along with total water vapor. This would provide stable measurements for Earth Science research that have previously been unattainable from geostationary orbit.

In FY 1997, continuing into FY 1998 and FY 1999, the following are significant accomplishments in the five priority areas on which Earth Science program science is focusing:

- The land cover/land use priority area addressed the role of the boreal forest in global carbon cycle and the effects of land cover change in this region on global change. Studies on the scientific questions relevant to sustainable land management and the provision of ecological goods and services were conducted. The objective was to develop the capability to perform repeated global inventories of land-cover and land-use from space, and to develop the scientific understanding and models necessary to evaluate consequences of observed changes. Comparisons of and improvements upon productivity and land cover models will focus on improving the portrayal of transient effects and on incorporating data from EOS AM-1 satellite sensors.

- Research in the short-term climate focused on improved understanding of key interactive climatic processes, such as between the ocean and atmosphere, that should lead to an enhanced ability to predict significant variations in the system, including ones that are geographically specific. Predictions of the consequences of these variations on ecosystems and on socio-economic interests should be enabled. The economic value of useful predictions of events like El Niño and its various regional effects in the United States can be measured in proportion to the considerable impacts of such transient climatic anomalies.

- The long-term climate system variability program emphasized observations and analysis of on-going variations in present climates and their impacts on the environment, in order to improve the understanding of climate processes to the point where useful predictions of regional climate change can be made. This enhanced understanding will enable the early detection of climate trends, the separation of natural variability from forced climate changes, the quantification of sources and sinks of greenhouse gases, the determination of the main climate feedback processes, and diagnosis of the thermal energy, water, ozone, and carbon cycles that couple the main components of the climate system.

- The natural hazards program's science research priorities were in selected aspects of disaster reduction where the technology pathway is understood and significant advances may be anticipated within a decade. Deliverables products and scientific progress will include: assessment of the application of precise correlation between surface deformation and seismic or volcanic events and transfer of the operational responsibility for these observations to operational organizations.

- NASA research continued to characterize the global distribution of ozone, chemically active trace constituents, aerosols, and related meteorological parameters (e.g. temperature), including long-term observations of a subset of these parameters. The purpose is to understand the processes responsible for the chemical transformations of trace constituents, the role of aerosols in affecting atmospheric chemistry, and the transport of trace constituents within the stratosphere, between different atmospheric levels (stratosphere/troposphere, stratosphere/ mesosphere), and between the troposphere and the earth's surface. It also will quantitatively model the trace constituent composition of the troposphere/stratosphere system through the combined application of observations and global models.

The EOS, the centerpiece of Earth Science, is a program of multiple spacecraft (the AM, PM, Chemistry, Landsat-7, and follow-on and supporting technology) and interdisciplinary science investigations to provide a 15-year data set of key parameters needed to understand global climate change. The first EOS satellite launches begin in 1998. Preceding EOS are a number of individual satellite and Shuttle-based missions which are helping to reveal basic processes. UARS, launched in 1991, collects data on atmospheric chemistry. The TOMS instruments, launched in 1978, 1991, and 1996, measure ozone distribution and depletion. Two TOMS instruments were launched in 1996, one on the Japanese Advanced Earth Observing System (ADEOS) mission and the other on a dedicated United States earth probe. France and the United States collaborated on the Ocean TOPEX/Poseidon, launched in 1992, to study ocean topography and circulation. The NASA Scatterometer (NSCAT) mapped ocean winds for one year prior to an on-orbit failure of the Japanese ADEOS-I spacecraft on June 30, 1997. In 1997, the TRMM was launched to provide the first-ever measurements of tropical precipitation. (Figures NASA-1, NASA-2, and NASA-3) Complementing EOS will be a series of small, rapid development ESSP missions to study emerging science questions and to use innovative measurement techniques in support of the 15-year mission of EOS. The first two ESSP missions, Vegetation Canopy Lidar (VCL) and Gravity Recovery and Climate Experiment (GRACE), were selected and are scheduled for launch in 2000 and 2001, respectively.

Data from Earth Science missions, both current and future, will be captured, processed into useful information, and broadly distributed by the EOSDIS. EOSDIS will ensure that data from these diverse missions remain available in active archives for use by current and future scientists. Since these data are expected to find uses well beyond the Earth Science research community, EOSDIS will ultimately be accessible by environmental decision-makers, resource managers, commercial firms, social scientists and the general academic community, educators, state and local government--anyone who wants the information. Following the recommendation of the National Research Council, NASA is exploring the creation of a federation of Earth Science information partners in academia, industry and government to broaden the participation in the creation and distribution of EOSDIS information products. As a federation pilot project, 24 organizations were competitively selected in December 1997 to become Earth Science Information Partners to develop innovative science and applications products.

A new generation of Earth Science will begin with the successful launch and checkout in 1998 of EOS AM-1 - one that studies the earth as a global system. Because the AM-1 spacecraft primarily observes terrestrial features, a morning equatorial crossing time is preferred to minimize cloud cover over land. EOS AM-1 will carry a complement of five synergistic instruments. The Clouds and Earth's Radiant Energy System (CERES) instrument will perform measurements of the earth's "radiation budget" or the process by which the earth's climate system maintains a balance between the energy that reaches the earth from the sun, and the energy that radiates from earth back into space. The components of the earth system that are important to the radiation budget are the planet's surface, atmosphere, and clouds. The Multi-angle Imaging Spectroradiometer (MISR) will measure the variation of the surface and cloud properties with the view angle. Meanwhile, the Moderate-Resolution Imaging Spectroradiometer (MODIS) will measure atmosphere, land, and ocean temperature, and moisture profiles, snow cover and ocean currents. The Canadian Measurements of Pollution of the Troposphere (MOPITT) instrument is an infrared gas-correlation radiometer that will take global measurements of carbon monoxide and methane in the troposphere. The Advanced Spaceborne Thermal Emission and Reflection

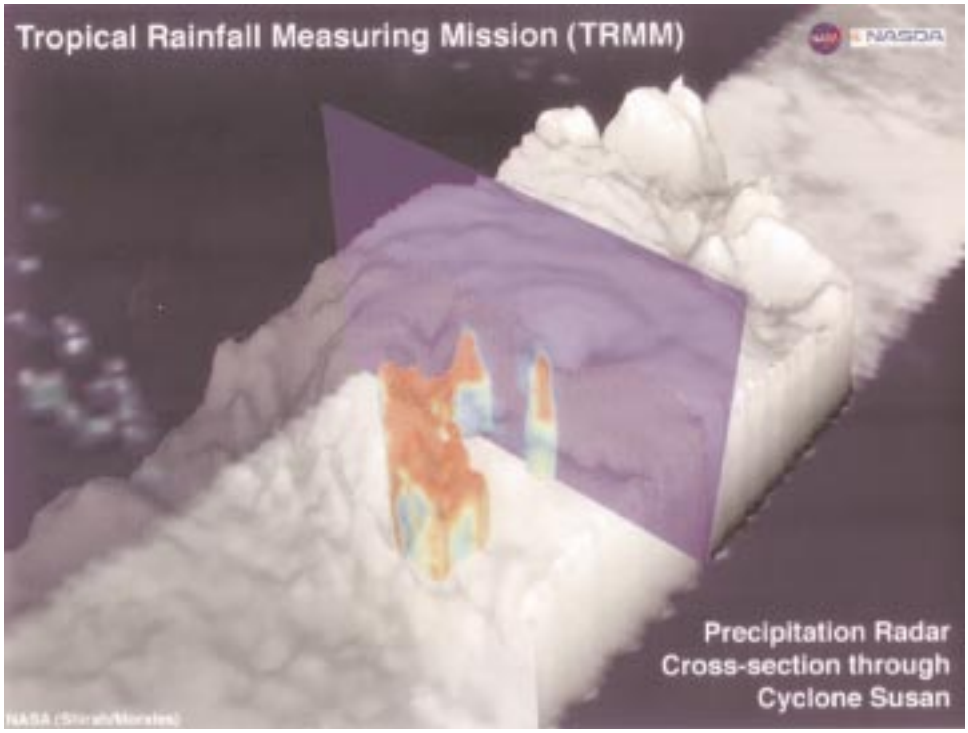

Figure NASA-1. TRMM slicing through clouds of Tropical Cyclone Susan on January 10, 1998. Researchers are examining TRMM data of Tropical Cyclone Susan and Supertyphoon Paka to determine if increased convection in the eyewall is indeed the forebearer of cyclone intensification as predicted by many models.

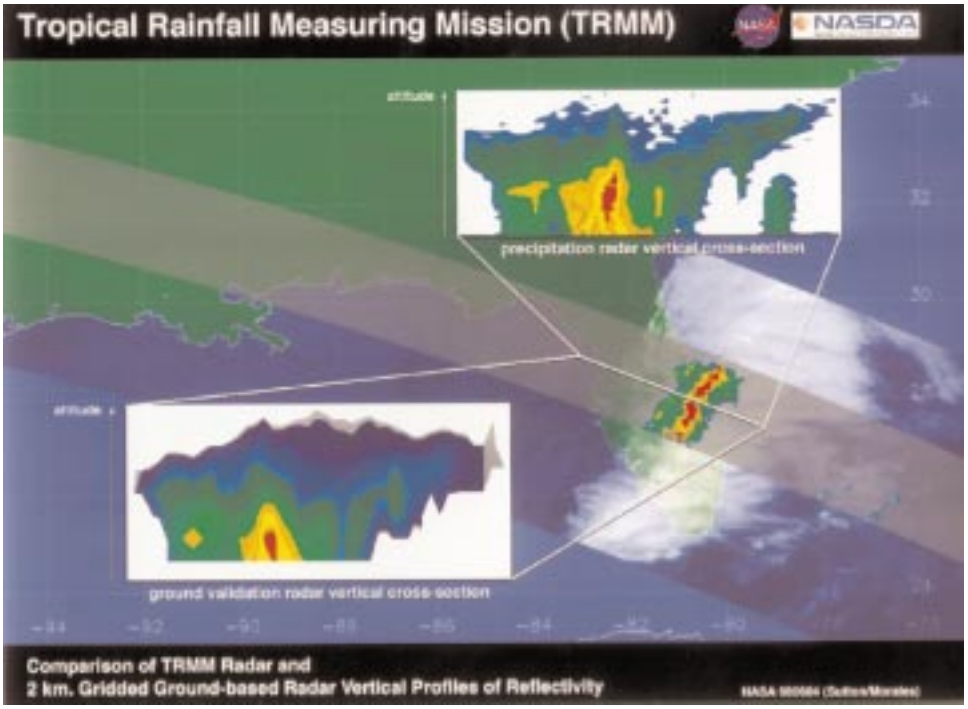

Figure NASA-2. Line of severe thunderstorms moving across Florida on March 9, 1998. The radar reflectivity seen by the TRMM satellite is compared to the WSR-88D at Melbourne, Florida. The Melbourne site is used as a TRMM ground validation site. TRMM radar data is able to give more detailed vertical profile of the storm.

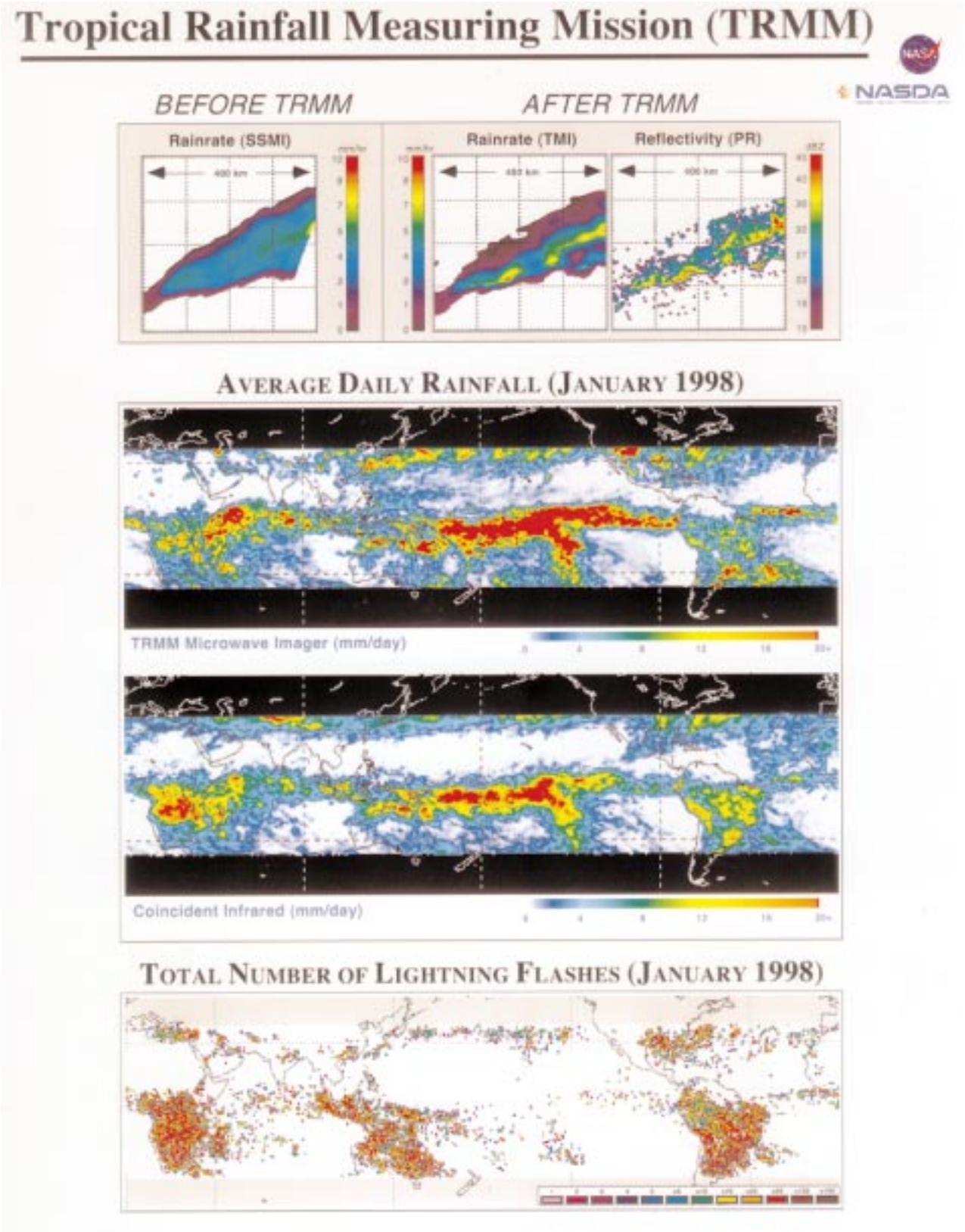

Figure NASA-3. Top panel: The rainfall was captured simultaneously by TRMM and SSM/I in the northern Pacific (32oN 165oE). Middle and bottom panels: Preliminary rainfall estimates based upon passive microwave and IR techniques. Notice the biases (land/ocean) between TMI and IR perfectly mirror the areas with lightining.

NASA's Tropical Rainfall Measuring Mission (TRMM)
Observes El Niño Rainfall Patterns

Since its launch in November 1997, NASA's Tropical Rainfall Measuring Mission has observed the rainfall patterns of the Earth's tropical belt with advanced instrumentation including a precipitation radar, a high-resolution passive microwave radiometer, and a visible/infrared cloud imager. TRMM is also being used to calibrate rainfall estimates from other satellites. The precipitation information from all the satellites, including TRMM, polar-orbiting satellites, and geosynchronous satellites, is merged into a precipitation analysis product. This combined product incorporates the accuracy of the TRMM sensor suite and the frequent sampling of precipitation from the other satellites. As a final step, information from rain gauges is also included in the analysis.

In Figure NASA-4, the top panel shows the first TRMM Merged Precipitation Analysis (1^o latitude x 1^o longitude resolution) for the month of January 1998. Clearly evident is the Inter-Tropical Convergence Zone (ITCZ) running along the Equator and mid-latitude maxima in the Northern Hemisphere between 30^o and 40^oN. There is a substantial area of rainfall rates of over 20mm per day over the central Pacific Ocean.

The middle panel shows the January climatology from the Global Precipitation Climatology Project (GPCP); GPCP is the current (pre-TRMM) standard of the global precipitation research community.

The bottom panel shows the deviation of the TRMM-based January 1998 analysis from the climatology. The resulting field shows the impact of the El Niño phenomenon. The central Pacific Ocean has a substantial positive anomaly along and to the south of the Equator with a deficit just to the north where the ITCZ is usually located. Farther afield, there are significant positive anomalies in the western Indian Ocean, along the northern edge of Australia, across southern Japan and into the Pacific storm belt, and along the western and eastern coasts of the United States. Significant deficits of rainfall are noted across the eastern Indian Ocean and Indonesia and over the Amazon forest and the adjacent Atlantic Ocean.

As the analysis of the TRMM data proceeds, fields such as these will be refined and validated and later compared carefully with "conventional" GPCP analyses leading to a much more accurate estimation of tropical rainfall variations and climatologies based on the new information from TRMM.

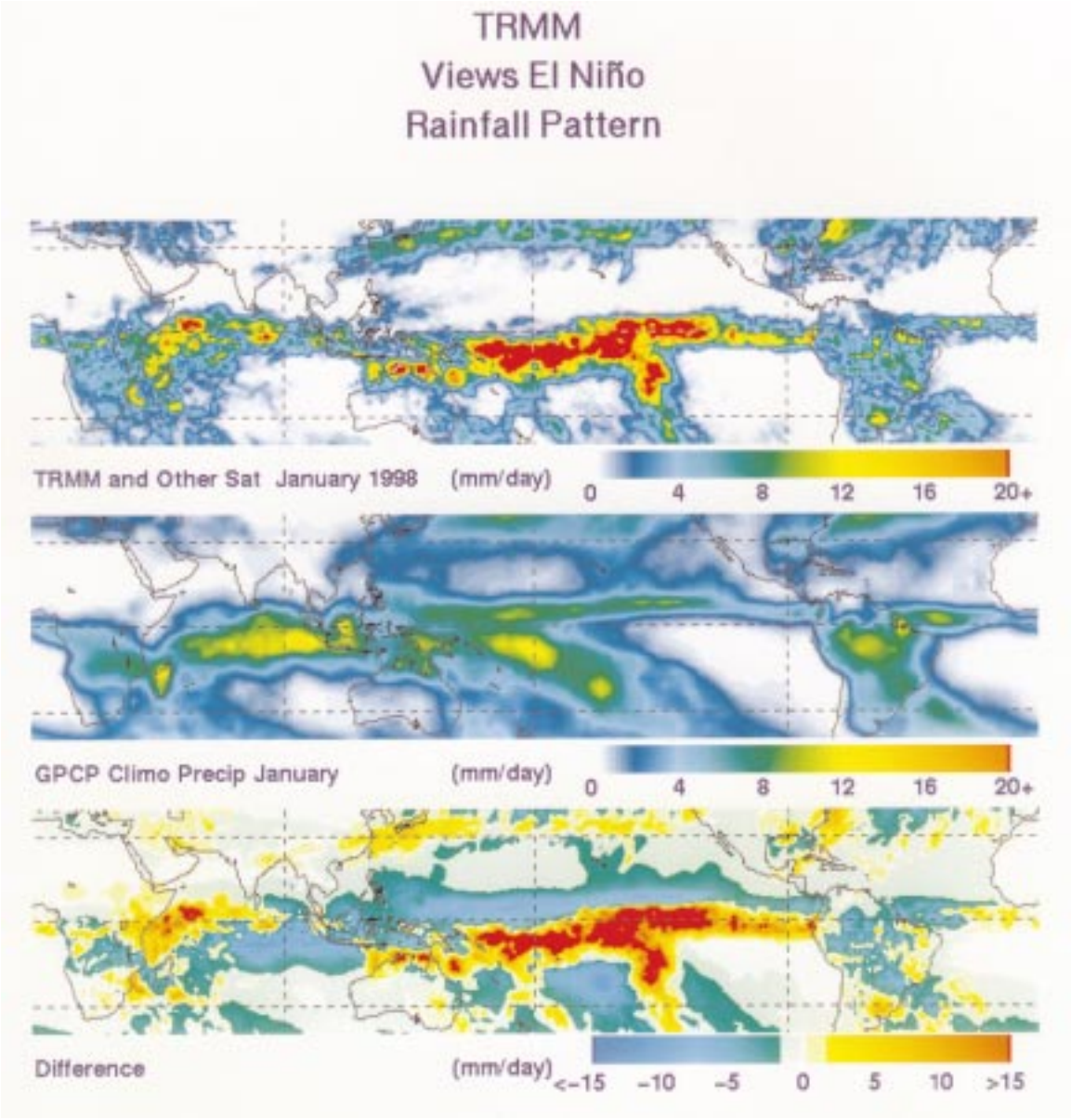

Figure NASA-4. TRMM observes El Nino rainfall patterns.

Radiometer (ASTER), provided by Japan, will measure cloud properties, vegetation index, surface mineralogy, soil properties, surface temperature and obtain digital elevation modes. The primary contractors associated with the program are Lockheed Martin Missiles and Space for the AM-1 spacecraft, Hughes Santa Barbara Remote Sensing (SBRS) for the MODIS instrument, TRW for the CERES instrument (the instrument has also been flown on the TRMM in 1997 and will fly on the PM spacecraft), and Lockheed Martin Commercial Launch Services for the AM-1 Atlas Centaur/IIAS launch service.

The research focus of the PM-1 spacecraft is atmospheric temperatures and humidity profiles, clouds, precipitation, and radiative balance; terrestrial snow and sea ice; sea-surface temperature and ocean productivity; soil moisture; and the improvement of numerical weather prediction. With the emphasis of the instrument complement being cloud formation, precipitation, and radiative properties, an afternoon equatorial crossing is more suitable for acquiring the data. The primary contractors associated with the program are TRW for the common spacecraft to be used for PM-1; Lockheed Martin Infrared and Imaging Systems (LMIRIS) and Joint Propulsion Laboratory (JPL) for the Advanced Infrared Sounder (AIRS) instrument; and Aerojet for the Advanced Microwave Sounding Unit (AMSU) instrument. Japan will provide the AMSR instrument for the PM-1 spacecraft and Brazil will provide a microwave instrument, the HSB. The launch of PM-1 is scheduled for December 2000.

The study area for the Chemistry-1 will be atmospheric chemical species and their transformations. The Tropospheric Emission Spectrometer (TES) and the Microwave Limb Sounder (MLS) instruments are planned to be built in-house at JPL. TRW is the contractor for the Chemistry-1 common spacecraft to be used also for PM-1 The University of Colorado and Rutherford Appleton Laboratory/Oxford University in the United Kingdom will provide the High Resolution Dynamics Limb Sounder (HIRDLS) instrument for the Chemistry-1 spacecraft. Preliminary discussions are currently under way with the Dutch for a possible ozone measuring instrument. The launch of Chemistry-1 is scheduled for December 2002.

The next generation of EOS missions will provide new technology and space systems to meet the scientific needs for the NASA Earth Science programs. Systematic and process measurements will be defined to support the five science theme areas. New instrument technologies will be tested, validated, and made available to support science proposals for selection of measurements, principal investigators, and instruments for the next EOS missions. All EOS measurements, principal investigators, and instruments will be selected as a result of a broad agency announcement that will include peer review, with the goal of a first planned follow on launch for FY 2004. Launches are expected each year through 2009.

The scientific objectives of the TOMS program are to measure the long-term changes in total ozone and to verify the chemical models of the stratosphere used to predict future trends. The TOMS flights build on the experience that began in 1978 with the launch of a TOMS instrument (flight model 1) on Nimbus-7 and continued with the TOMS instrument (flight model 2) on a Russian Meteor-3, launched in 1991. As with the earlier developments, Goddard Space Flight Center (GSFC) has the responsibility for flight project development, and post-launch mission operations and data analysis. The prime contractor is the Orbital Sciences Corporation for the TOMS instruments and Pegasus launch services. The remaining development TOMS program consists of one instruments (flight model 5, designated FM-5). The FM-5 has been completed, is in storage, and is scheduled to fly as a cooperative mission with Russia in August 2000.

The latent heat released during precipitation is a significant factor in the large-scale computer models used to predict weather and climate change, yet two-thirds of the global rainfall occurs over the tropics where rain measurements are scarce. The TRMM objective is to obtain a minimum of three years of climatologically significant observations of tropical rainfall. In addition, TRMM will provide precise estimates of the vertical distribution of latent heat in the atmosphere. The TRMM data will be used to understand the ocean-atmosphere coupling, especially in the development of El Niño events, which form in the tropics but effects of which are felt globally, causing floods in some areas, yet droughts in others. GSFC has the responsibility for post-launch mission operations and data analysis. The TRMM was launched aboard the Japanese H-II vehicle November 27, 1997.

In late 1998, QuikScat will be launched to fill the gap in critical sea surface wind data resulting from the

on-orbit failure of the Japanese ADEOS-I spacecraft in June 1997. NASA has accelerated the availability of components of the Seawinds instrument originally planned for launch on Japan's ADEOS II mission as a QuikScat instrument. The launch of QuikScat will reduce a gap of as great as 3 years in sea winds data from the loss of ADEOS-I by as much as 24 months. Japan has yet to decide on the timing and form of an ADEOS II mission (or missions), but Earth Science still intends to fly a Seawinds instrument in that context as the follow-on instrument to QuikScat. This approach will enable continuity of the ocean winds data set for its many users. In parallel to this development effort, a data buy solicitation for ocean and wind vector data is being initiated.

The measurements to be made by these and other future Earth Science missions as well as current on-orbit missions provide data products that are used extensively in the Earth Science program. The program encompasses over 1,700 scientific activities at universities, research laboratories, and government research organizations. These activities are providing an ever increasing scientific understanding of global environment and the effects of natural and human sources of change.

AVIATION WEATHER RESEARCH

NASA is performing research that will substantially improve the display of weather information in the cockpit, will provide dramatic improvements in synthetic vision (electronic vision aids to see at night in poor visibility), turbulence detection and icing protection. The research applies to commercial aviation as well as general aviation. Some of the research makes extensive use of data from the Global Positioning System (GPS) satellite network.

Aviation Safety Program

NASA's Aviation Safety Program is aggressively pursuing three primary areas:

- Aviation Weather Information Distribution and Presentation: This includes combining the inputs from a variety of sources of weather data into a convenient, cockpit display that is simple and easy for the pilot to comprehend. It will likely be a multifunction flat panel display that will display all forms of weather, terrain and traffic hazards. The Advanced Air Transport Technology element is contributing the early work here in hazard avoidance displays and planning.

- Synthetic Vision in the Cockpit: This is the development of electronically enhanced vision which "fuses" the inputs from television, infrared, Lidar, and radar sensors into a single head-up-display (HUD) the pilot will look through as he or she looks out the window. This see-through HUD will make the world look like a bright sunny day even when the airplane is approaching a fogged-in airport at midnight--one that would be shut down under today's operating rules.

- Turbulence Detection: This is the development of aircraft-mounted, forward looking turbulence detectors that look several kilometers ahead of the aircraft using Lidar (and perhaps radar) technology. A suitable cockpit warning device would alert pilots of impending encounters. There is also work in ground based detection.

NASA's Icing Research is pursuing a large number of areas that affect aircraft in flight. Primary examples of this effort are:

- The development of icing training videos and other materials will help educate pilots on all aspects of aviation icing.

- The development of improved wind tunnel and analytical techniques to predict icing accumulation patterns on wings, tails and inlets will help designers improve future aircraft and engines.

- Forward looking, aircraft mounted detectors will detect moisture laden clouds miles ahead of the aircraft. Adding air temperature, pressure and humidity to the data received from the sensors, on board computers will compute the icing potential of the approaching cloud and will display "high risk areas" to the pilot in an easily read, color cockpit display.

- Sensors that measure the accumulated ice on aircraft in flight will automatically activate, new, low cost de-icing devices that will shed the ice before the aircraft gets in danger.

- The potential for satellite detection of icing conditions is being investigated.

General Aviation

NASA's General Aviation element is actively researching new, low power and low cost pneumatic

and electrical ice removal technology. Also in development are low cost displays that graphically show icing weather information so icing conditions can be avoided during flight planning.

Terminal Area Productivity

NASA's Terminal Area Productivity element is contributing via these areas:

- Wake vortex detection to improve the efficiency of aircraft spacing.

- A heads up display that electronically displays the edges of taxiways and runways, shows ground traffic and marks clearance routes to gates and/or runways. All this is overlaid on the pilot's "real world" view out the window while stereo headphones allow the pilot to hear ground traffic from the direction the other aircraft really are. This will be a great aid to vision in poor visibility--especially at unfamiliar airports.

- A look down electronic display shows a bird's eye view of the airport as if the pilot were looking at the airport on a bright sunny day from about 200 feet above the airport. The position of all runways, taxiways, buildings and ground traffic is clearly displayed--as is the exact route the pilot is cleared to take to get to the gate or the runway. Another huge aid to vision in bad weather.

As with virtually all of NASA's aviation research, most of the research mentioned above also helps pilots in good weather too.